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TR 64-136

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TECHNICAL REPORT NO. 64-136

SEMIANNUAL PROGRESS REPORT NO. 8, PROJECT VT/072

1 July through 31 December 1964

IMPROVED SEISMOGRAPHS

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GEOTECH

THE GEOTECHNICAL CORPORATION

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~~TECHNICAL REPORT NO. 64-136~~

9 SEMIANNUAL PROGRESS REP[redacted]T. NO. 8, [redacted]
1 Jul[redacted]-31 Dec[redacted]64,

6 IMPROVED SEISMOGRAPHS.

~~by~~

10 Frank Kissinger,

11 30 Dec 64,

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14 TR-64-136

15 AF~~~~33(657)-9967, ARPA Order-104-60

16 AFTAC-VT/072

THE GEOTECHNICAL CORPORATION
3401 Shiloh Road
Garland, Texas

~~30 December 1964~~

(154 050)

IDENTIFICATION

AFTAC Project: VT/072
Project Title: Improved Seismographs
ARPA Order No: 104-60
ARPA Code No: 8100
Contractor: The Geotechnical Corporation, Garland, Texas
Date of Contract: 1 November 1962
Amount of Contract: $852,675.00
Contract Number: AF 33(657)-9967
Contract Expiration Date: 31 October 1964
Project Engineer: J. R. Womack, BR8-8102

SEMIANNUAL PROGRESS REPORT NO. 8, PROJECT VT/072
1 July through 31 December 1964

This report covers the work accomplished on Project VT/072 during the 6-month period ending 31 December 1964. Final technical reports on instruments developed during the reporting period have been completed.

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ILLUSTRATIONS

FINAL SEMIANNUAL PROGRESS REPORT NO. 8, PROJECT VT/072
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IMPROVED SEISMOGRAPHS

1. SUMMARY

A copy of the "Statement of Work" of Project VT/072, Contract AF 33(657)-9967, is included in the appendix of this report. A brief description of the work accomplished on each task is given below. Specific details are given in succeeding paragraphs.

1.1 INCLINED SEISMOMETERS, TASK 1a

Assembly of the short-period (deep-hole) triaxial seismometer was not completed. Problems were encountered with the transducer and a theoretical investigation of the transducer design was performed. Results from this investigation indicate that the present transducer is not workable in the instrument. A technical report (TR 64-126) titled Short-Period Deep-Hole Triaxial Seismometer was completed and 50 copies were sent to AFTAC for distribution.

The design, assembly, and laboratory testing of the long-period (shallow-hole) triaxial seismometer were completed during the last reporting period. The technical report (TR 64-69) titled Melton Long-Period Bore-Hole Triaxial Seismometer was completed and 50 copies were sent to AFTAC for distribution.

The technical report (TR 64-58) titled Coordinate Transformer, describing the electrical networks (which permit alteration of the directions sensed by the triaxial seismometer while operating in a deep-hole), was completed during the last reporting period and 50 copies were sent to AFTAC for distribution.

1.2 GALVANOMETERS, TASK 1b

Operational tests on the moving-magnet galvanometer were performed to determine the free period of the instrument, current sensitivity, and response to various damping conditions.

Construction of the dynamometer-type galvanometer was completed and operational tests were performed.

Theoretical investigation of multiple-reflection arrangements and lens-mirror combinations in galvanometers was completed during the reporting period.

The technical report (TR 64-133), titled Galvanometers, describing the moving-magnet galvanometer, improved galvanometer resolution, and power-level galvanometer, was completed and 50 copies were sent to AFTAC for distribution.

1.3 FILTERING, TASK 1c

Technical reports titled Variable Filter (TR 64-41) and Dual Galvanometer Seismograph (TR 64-32) were completed during the last reporting period and 50 copies were sent to AFTAC for distribution. These reports complete the contractual requirements for this task.

1.4 AMPLIFIERS, TASK 1d

Assembly and laboratory testing of the PCA and solid-state dc amplifier were completed during the last reporting period. Technical reports titled Low-Level Low-Frequency Photocell Amplifier (TR 64-71) and Low-Level Low-Frequency Solid-State Amplifier (TR 64-73), describing these instruments, were completed and 50 copies sent to AFTAC for distribution. The technical report titled Induction Modulator Amplifier (TR 64-43) was completed during the last reporting period and 50 copies were sent to AFTAC for distribution. These reports complete the contractual requirements for this task.

1.5 DIGITIZER, TASK 1e

The technical report titled Short-Period Digitizer (TR 64-65), describing this instrument, was completed during the last reporting period and 50 copies

were sent to AFTAC for distribution. Design and construction of the digital film recorder continued, and the instrument is approximately 75% complete. The reader-converter portion of the system is approximately 25% complete.

1.6 NEW METHODS OF SIGNAL PRESENTATION, TASK 1f

A technical report titled Array Processor and Lissajous Display (TR 64-69) was completed during the last reporting period and 50 copies were sent to AFTAC for distribution.

1.7 IMPROVED SEISMOGRAPH TESTING FACILITIES, TASK 1g

The technical report titled Improved Shake Table System (TR 64-78) was completed and 50 copies were sent to AFTAC for distribution.

1.8 STABLE TABLE, TASK 1h

The technical report describing the single-degree-of-freedom stable table titled Stable Table (TR 64-70) was completed during the reporting period and 50 copies were sent to AFTAC for distribution.

1.9 STRAIN SEISMOGRAPH, TASK 1i

The technical report of the strain seismograph titled Horizontal Strain Seismograph (TR 64-54) was completed during the last reporting period and 50 copies were sent to AFTAC for distribution. This report completed the contractual requirements for this task.

1.10 INVESTIGATION OF THERMAL NOISE, TASK 1j

Work continued on the fabrication and assembly of the torsional pendulums. A technical report titled Interim Report on the Experimental Investigation of Thermal Noise (TR 64-127) was prepared on the status of this investigation and 50 copies were sent to AFTAC for distribution.

2. INCLINED SEISMOMETERS, TASK 1a

2.1 SHORT-PERIOD TRIAXIAL SEISMOMETER

A complete theoretical analysis of the present variable-reluctance transducer was performed in an effort to determine the source of difficulty. The analysis showed that the present transducer configuration is not workable in the instrument. The major source of difficulty centers around the available coil space in each coil cup. A larger coil with more ampere turns is needed to critically damp the mass when the seismometer is operated in a deep hole. The transducer is mounted at an oblique angle to the case which prohibits increasing the size of the coil cups to incorporate a larger coil. Any new transducer design will require modifications to the other seismometer components because of the interrelationship that exists between the transducer and the mass. A technical report was prepared which describes the present status of the seismometer and recommends further work needed to make the instrument operational. Fifty copies of this report were sent to AFTAC in December for distribution

2.2 LONG-PERIOD TRIAXIAL SEISMOMETER

Development on the long-period triaxial seismometer was completed during the last reporting period. A technical report describing the development of this instrument (including laboratory tests) was completed and sent to AFTAC for distribution early in the reporting period.

This seismometer (figure 1) has been constructed to operate on the bottom of holes up to 45 m deep. The instrument is 0.3 m in diameter, 0.6 m high and weighs 115 kg. Three mass-spring suspensions within the instrument have three orthogonal axes of sensitivity with respect to earth motion. The natural frequency is adjustable from 0.05 to 0.1 Hz. The 1000-Ω moving-coil transducer has a generator constant of 135 V/m/sec which produces the required electromagnetic damping. Capability for remote calibration, mass lock, mass position, and natural frequency is provided.

Conclusions reached are:

a. The seismometer meets the three requirements for shallow-hole operation. It is small in diameter, and will fit inside a 0.457-m (18-in.) hole casing; it is adaptable for remote adjustment, and it is stable enough to operate unattended.

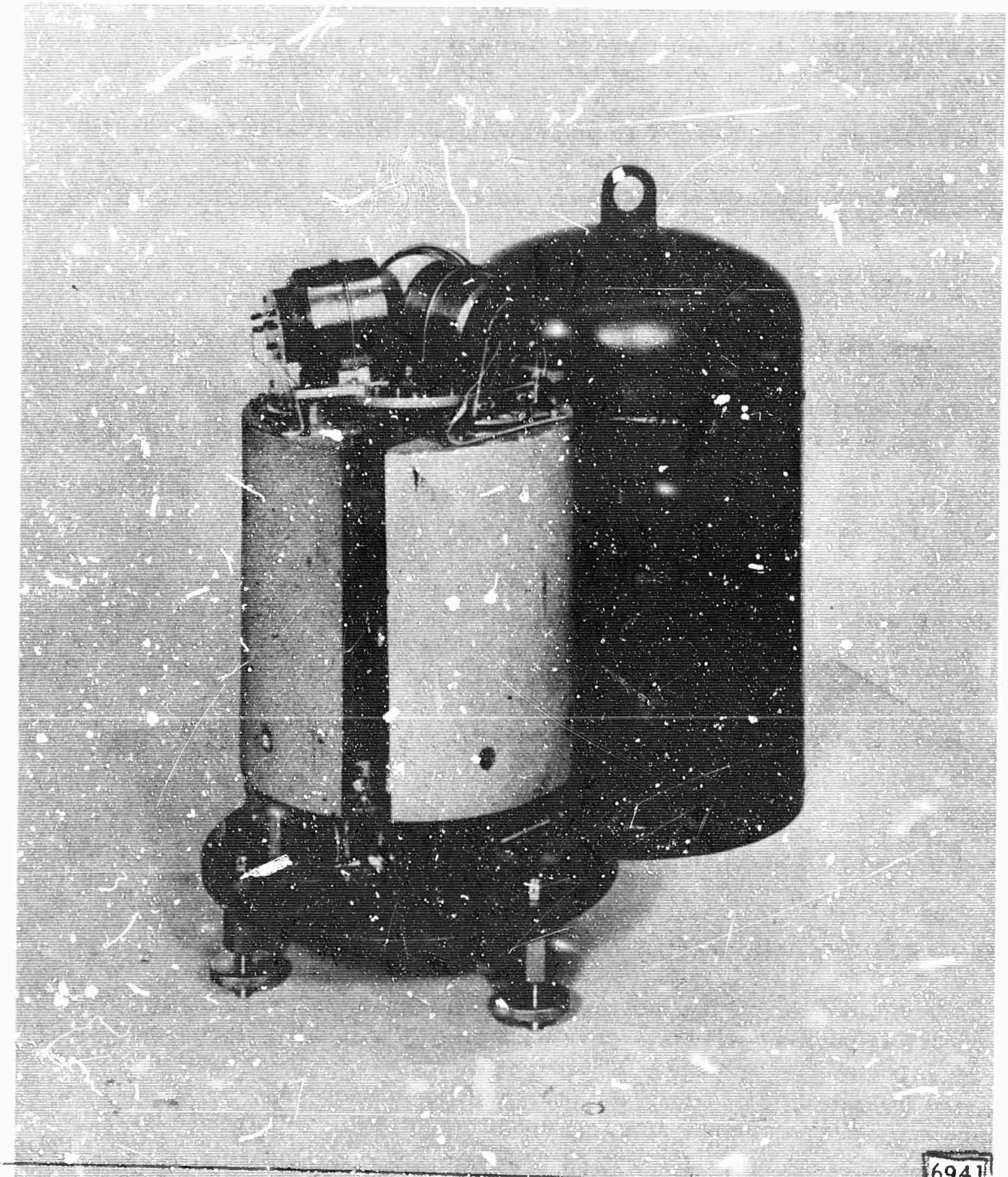

Figure 1. Melton long-period bore-hole triaxial seismometer

b. In its present form, the prototype seismometer is intended for pier operation. It must be leveled manually. The addition of a level sensor and remote controlled leveling jacks would be required for operation in a hole.

These features could easily be added with no modifications to the present configuration. Slight changes to the flexures and spring hangers would probably improve both linearity and stability.

2.3 ELECTRICAL NETWORKS

The coordinate transformer (figure 2) is designed to permit geographical leveling and orientation of triaxial seismograph systems. Three-component triaxial signals and signals equivalent to those of a conventional three-component seismograph are available at the coordinate transformer terminals.

The technical report describing the coordinate transformer was completed and 50 copies were sent to AFTAC for distribution.

The design objectives for the coordinate transformer have been met, with the exception of power consumption which is about 100 W greater than planned. Power consumption is high because of the extensive use of vacuum tubes and the precise voltage regulation required by the operational amplifiers. Satisfactory and dependable operation was noted during laboratory tests. No service problems have been encountered.

3. GALVANOMETERS, TASK 1b

3.1 REDUCE AIR DAMPING

Operational tests on the moving-magnet galvanometer were made during this reporting period. All tests were performed under laboratory conditions with the galvanometer mounted on a concrete pier and exposed to the unattenuated local magnetic field. The free period of the galvanometer, current sensitivity, and response to various damping conditions were determined.

The galvanometer exhibited a substantial amount of magnetic unbalance and had to be carefully oriented in the local magnetic field to minimize the magnetic spring. This magnetic spring was large enough to limit the length of

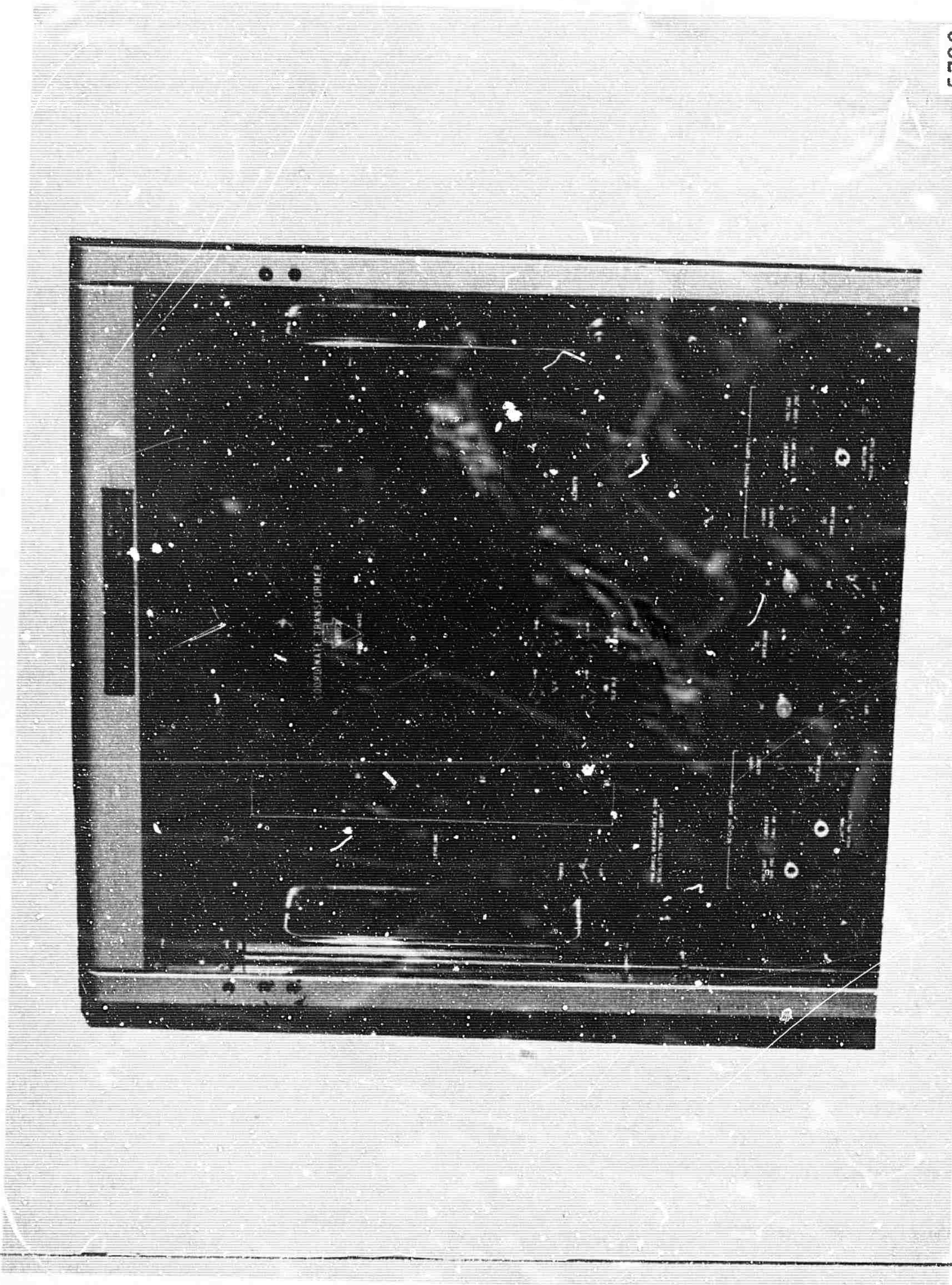

Figure 2. Coordinate transformer and power supply

the period in the test unit to 70 sec. The damping characteristics were tested both at room pressure and at a reduced pressure of 1×10^{-4} mm of Hg. The open-circuit damping decreased 56% at the reduced pressure. The open-circuit damping of 2.2% remaining after evacuation is attributed to losses other than those caused by air damping.

The following is a summary of the characteristics of the test galvanometer.

Free period (room pressure)	70.5 sec (small deflection)
Free period (reduced pressure = 1×10^{-4} mm of Hg)	70.2 sec (small deflection)
Mechanical spring constant	3.14×10^{-9} Nm/rad
Magnetic spring constant	3.086×10^{-8} Nm/rad
Moment of inertia of rotor (calculated)	4.28×10^{-6} kg m^2
Current sensitivity (parallel coil connection)	2.46×10^{-9} A/mm at 1m
Terminal resistance (parallel coil connection)	245 Ω
Open-circuit damping (room pressure)	5.0% of critical
Open-circuit damping (reduced pressure = 1×10^{-4} mm of Hg)	2.2% of critical
Closed-circuit damping (room pressure, parallel coil connection, circuit resistance = 245 Ω)	37.5% of critical
Closed-circuit damping (reduced pressure= 10^{-4} mm of Hg, parallel coil connection, circuit resistance = 245 Ω)	32.6% of critical
Focal length of galvanometer	99 mm
Diameter of mirror	9.5 mm

Physical characteristics	
Height	0.381 m (15 in.)
Diameter	0.184 m (7-1/4 in.)
Weight	1.99 kg (4.38 lb)

Technical Report No. 64-133, Galvanometers, Project VT/072, presents the findings of this task in detail.

3.2 POWER LEVEL GALVANOMETER

The construction of the dynamometer-type galvanometer was completed and a series of operational tests were performed.

Records were made of the galvanometer's response to sine wave and seismic inputs. The sine-wave response test was performed with the fixed and moving coils connected in series. The seismic response test was run using playback from magnetic-tape recordings of actual events. One record was made with the coils connected in series to give a power level representation of an earthquake. A second record was made (HARD HAT event) with the coils connected for multiplication-correlation. For this record, the vertical component of earth motion was connected to the moving coil and the horizontal component was connected to the fixed coil.

All tests were run with the galvanometer mounted in Photocell Amplifier, Model 16956 (see amplifiers, task 1d). Technical Report No. 64-133, Galvanometers, Project VT/072, presents the findings of this task in detail.

A summary of the characteristics of the dynamometer-type galvanometer follows.

Moving coil	
Number of turns	33.5
Terminal resistance (includes suspension ribbons)	29.0Ω
Resonant frequency (in air)	20.0 Hz
Resonant frequency (in fluid)	8.2 Hz
Sensitivity (series connection)	1.82×10^{-7} A^2/mm/m
Flat frequency response (0.7 critically damped)	0 to 4.8 Hz within 5%

Fixed coil	
Number of turns	11,780
Terminal resistance (two coils in series)	9,800 Ω
Rating (flux density between series connected coils)	53 T/A
Damping fluid	
Type	Silicone DC200
Viscosity (for 0.7 of critical damping)	2.044×10^{-5} m^2/sec
Density	955.0 kg/m^3
Refractive index	1.400
Optics	
Mirror size	1.59 mm wide x 6.35 mm long
Galvanometer focal length	125 mm
Galvanometer pupil (vertical plane)	0.873 rad (50 deg)
Physical	
Height	100 mm (3-15/16 in.)
Diameter	57.2 mm (2-1/4 in.)
Weight	0.296 kg (0.65 lbs)

3.3 HIGH-RESOLUTION GALVANOMETER

During the final report period, work was completed on multiple-reflection arrangements and on lens-mirror combinations in galvanometer optical systems. The final technical report was written, and the conclusions reached are:

The placement and form of optical elements following the galvanometer mirror have a significant effect on system sensitivity, so that alternate arrangements to the usual procedure of mounting a lens directly in front of the rotating mirror should be considered. A reflection-doubling mirror mounted close to the rotating mirror is the most promising method of increasing galvanometer sensitivity. A spherical rotating mirror will be practical if the ratio of the radius of rotation of the mirror to the radius of the mirror is close to unity.

4. FILTERING, TASK 1c

4.1 DUAL-GALVANOMETER SEISMOGRAPH

The development of the dual-galvanometer seismograph and TR 64-32, describing its development, were completed during the last reporting period. Fifty copies of the report were sent to AFTAC for distribution.

Results of laboratory tests (figure 3) show that the dual-galvanometer seismograph is a practical method of obtaining a wide-band response with the microseismic noise attenuated. It accomplishes this noise reduction by forming a rejection notch at the natural period of the seismometer. The position of the notch is easily adjusted.

Recommendations in the technical report suggested that field tests of the system should be performed to accomplish the following:

a. Determine the extent to which the available notch rejection properties increase the permissible system gain.

b. Determine if this method of noise rejection significantly improves the detection of seismic signals

c. Determine the stability of the notch characteristics under operational conditions.

4.2 ADJUSTABLE DATA FILTER

The adjustable data filter (figure 4) is a solid-state bandpass filter suitable for use in seismic observatories or seismic data-processing facilities. The instrument (designated Variable Filter, Model 16307) has adjustable cutoff frequencies and cutoff ratios that can be used for filtering data in real time or compressed time. The circuit elements consist of cascaded RC low- and high-pass filters. Front panel controls permit cutoff frequency selection and damping adjustment. Other desirable characteristics include an adjustable voltage gain up to 10, the ability to handle signals directly from vacuum-tube type phototube amplifiers (PTA), and selectable damping. The construction and laboratory testing of the prototype model of the variable filter was completed and TR 64-41 was written during the last reporting period.

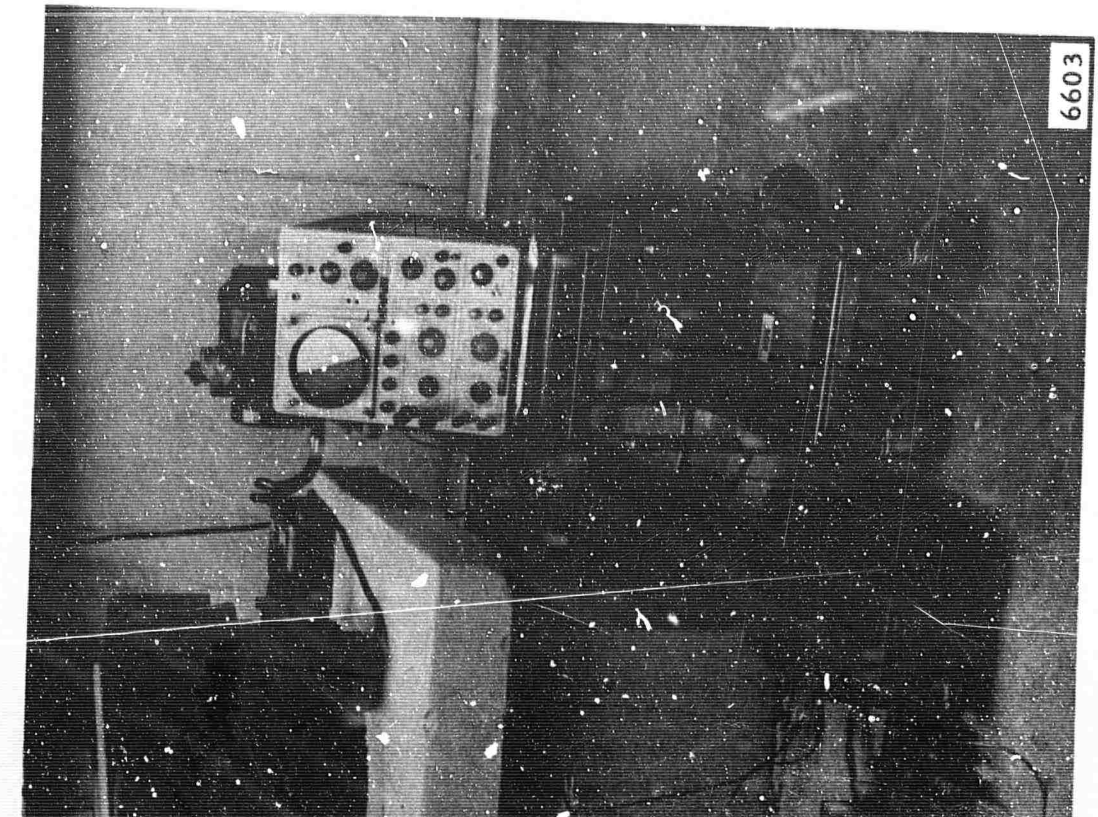

Figure 3. Dual-galvanometer seismograph on shake table

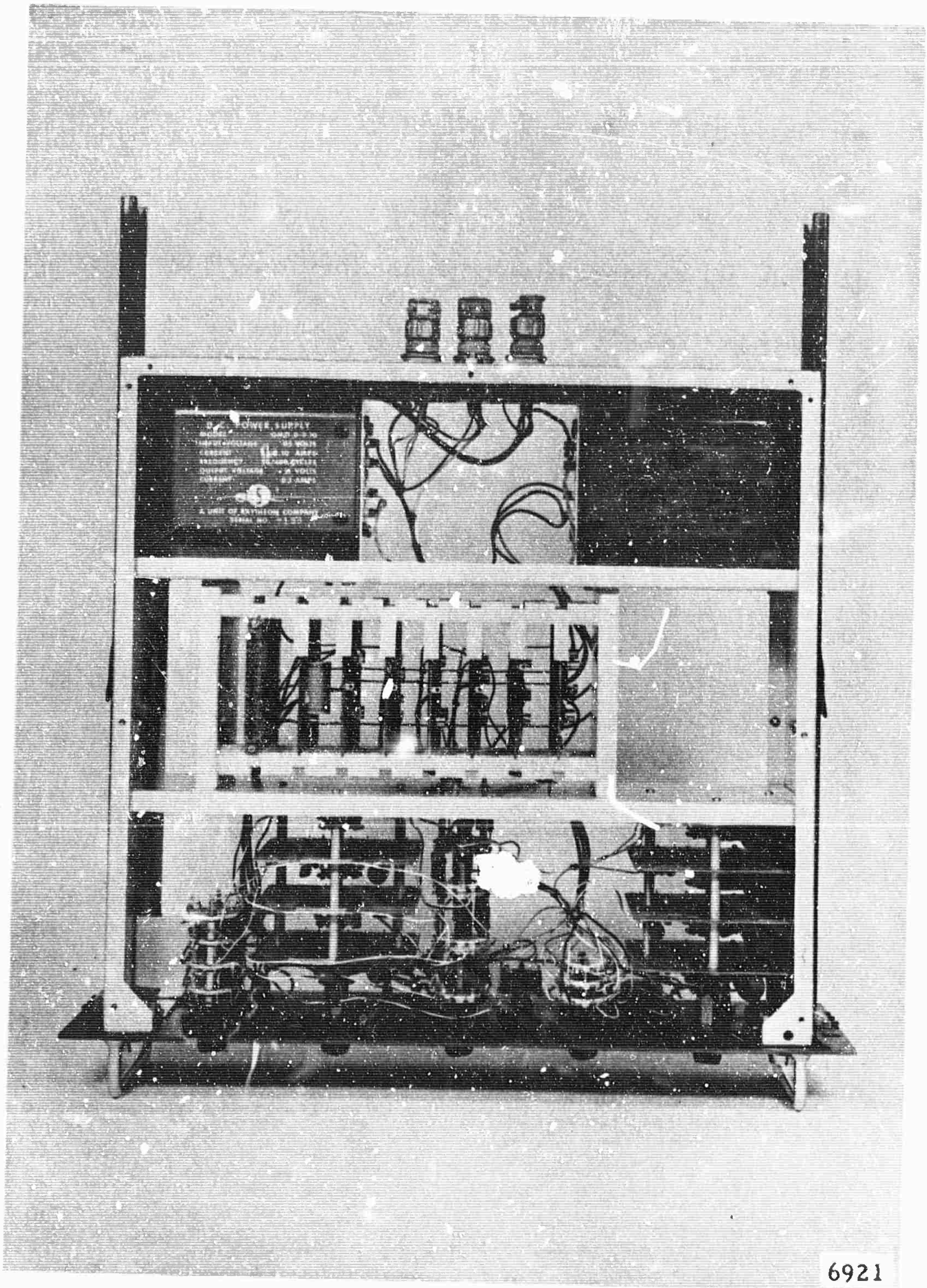

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Figure 4. Variable filter, top view, with dust covers removed

Conclusions are:

a. Based on the results of laboratory tests, the variable filter can be used to filter seismic data either at real-time frequencies or from high-speed magnetic-tape playback. Because of its phase shift, the filter can only be used as a flag when filtering seismic signals.[1]

b. To avoid waveform distortion, the filter should normally be operated in its critically damped mode. However, the maximally flat mode can be used where a wider passband is desired and ringing can be tolerated.

c. The INPUT switch in the LO position will allow bandedge-to-bandedge signals (3 V p-p) from FM tape recorders to be amplified by as much as 10 times. The HI position will allow maximum amplitude signals (20 V p-p) to be amplified up to 1.5 times. These features, along with a high-input impedance, make the filter useable in a variety of places in seismograph systems.

d. The operator does not have to think in terms of the actual playback frequencies involved while processing data in compressed time.

5. AMPLIFIERS, TASK 1d

5.1 ANALOG CODING PTA

The analog coding PTA (figure 5) low-level low-frequency Photocell Amplifier (PCA), Model 16956, was completed and laboratory tests were performed during the last reporting period. This instrument features either analog, broad-band FM carrier, or IRIG FM carrier output. A galvanometer with a high natural frequency is used in the input circuit for increased ruggedness, and signal frequencies up to 100 Hz may be amplified. The amplifier is capable of detecting a signal of 1.25×10^{-18} W in the bandpass from 0.01 to 5 Hz with a power requirement of less than 1.7 W. Signal common-mode

[1]The Geotechnical Corporation. 1963, Advantages of seismic data filters, Geotech Models 11760 and 12025, in preliminary seismic analysis: Technical Report No. 63-124

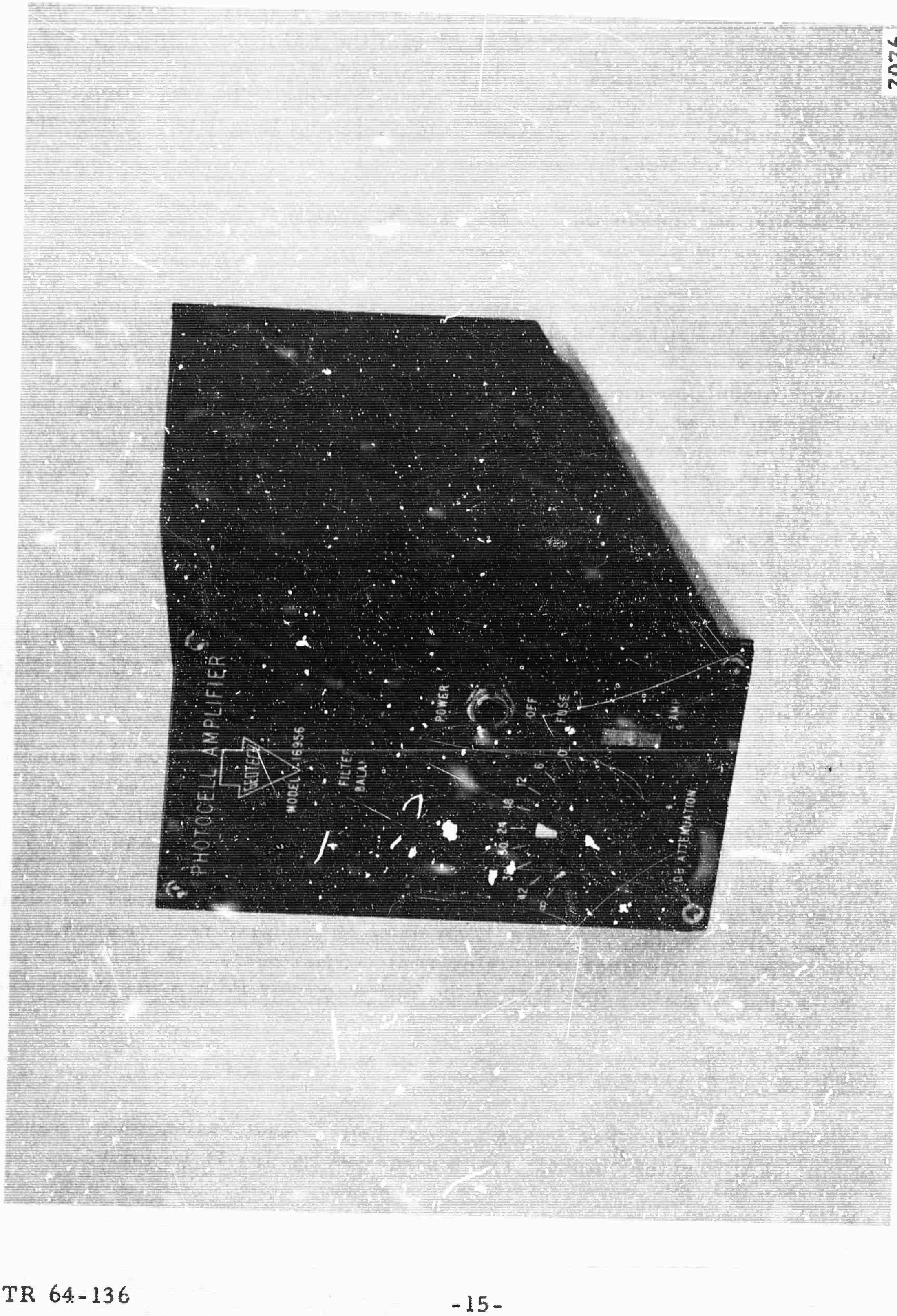

Figure 5. Photocell amplifier

rejection is greater than 140 dB, and the noise introduced by power-supply variations is negligible. Voltage gain of the PCA with analog output is 350K. With broad-band FM output in combination with the FM discriminator, the voltage gain is 1×10^6 with a dynamic range of 69 dB. Features include "floating" input, output, and power-supply connections. The instrument is packaged in a sealed case and contains solid-state and long-life components for long periods of unattended operation.

Technical Report No. 64-71 was written and 50 copies were sent to AFTAC for distribution early in this reporting period.

5.2 INDUCTION MODULATOR AMPLIFIER

The induction modulator amplifier (IMA) (figure 6) was conceived as a low-power substitute for phototube amplifiers in seismic instrument systems. A moving-coil modulator imposes modulation on a high-frequency carrier signal which is amplified by conventional solid-state amplifiers. A detector recovers the amplified low-frequency component of the modulated wave. Since no light source is required, power consumption is less than for a phototube amplifier; however, the noise level is greater and the circuit is more complex.

The induction modulator amplifier was completed and 50 copies of TR 64-43, describing the development of this instrument, were sent to AFTAC for distribution during the last reporting period.

Several conclusions were drawn as a result of laboratory tests on the amplifier. Compared to PTA's the IMA has lower gain, higher noise level, and greater complexity. However, it does have lower power consumption and slightly better resistance to seismic noise. With excitation voltage of 6 V p-p, the IMA has a nominal voltage gain of about 200K, compared with 700K for the low-power PTA, and a noise level of 0.3 μV rms, compared with less than 0.01 μV rms for the PTA. The IMA uses 26 transistors, compared to 17 for the PTA, and requires more electronic adjustments. Power consumption is approximately half that of the lowest power PTA presently available.

5.3 SOLID-STATE AMPLIFIER

The solid-state amplifier has either analog, broad-band FM carrier, or IRIG channel FM carrier output. The instrument (figure 7) was developed

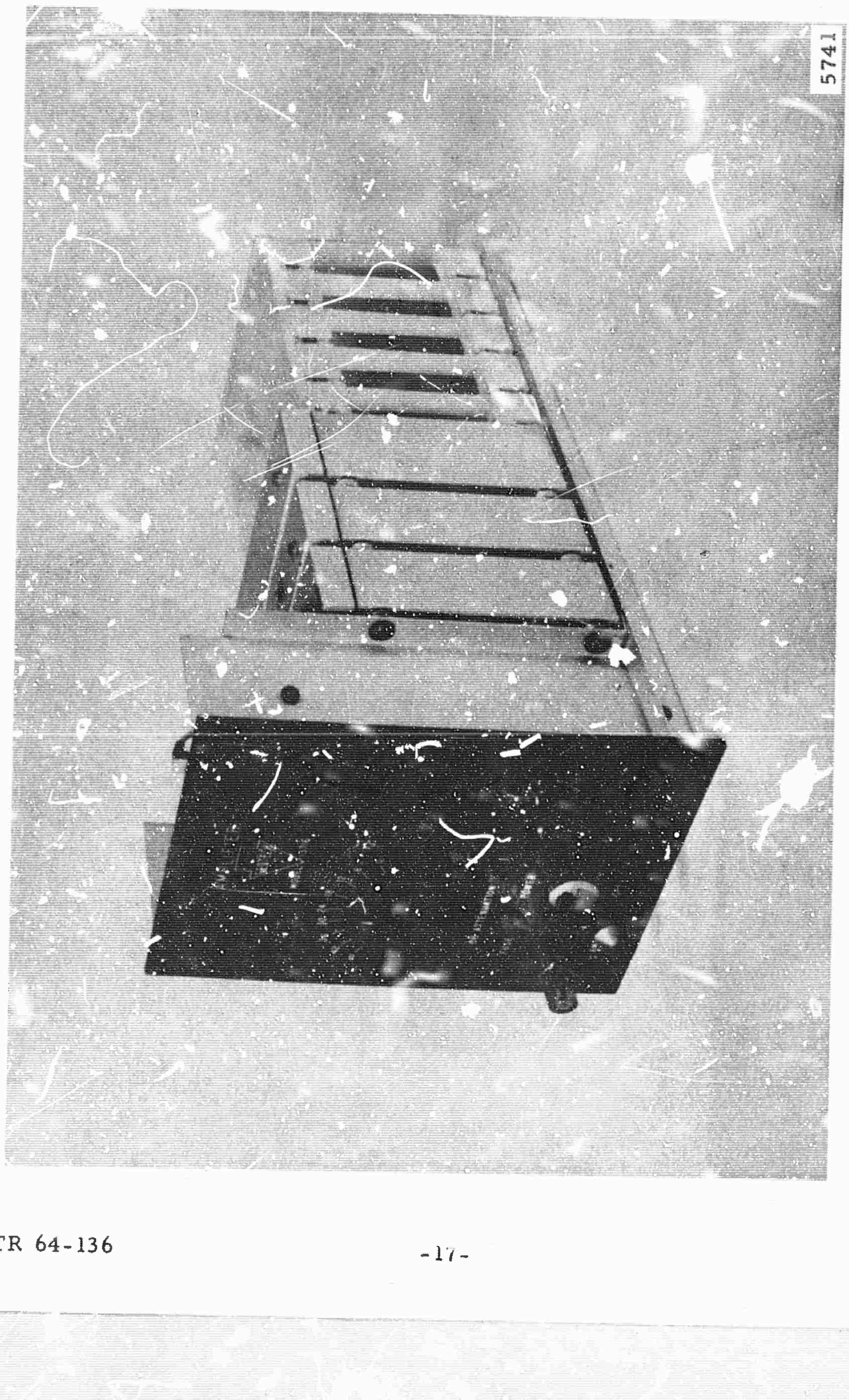

Figure 6. Amplifier chassis and front panel

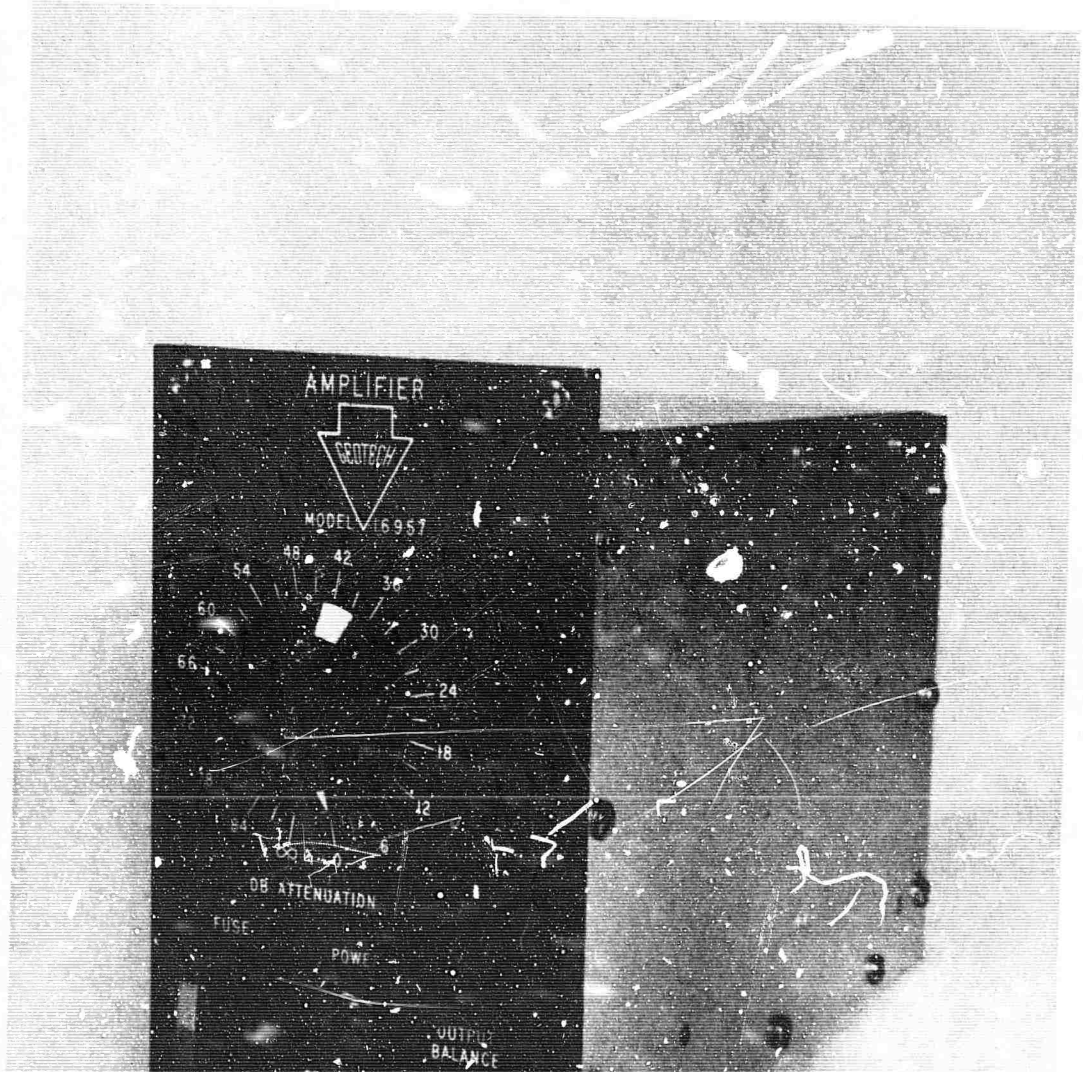

Figure 7. Solid-state dc amplifier

primarily for amplification of seismic signals in geographic areas where the low-noise capability of a PTA is not required. The amplifier is capable of detecting a signal of 2.5 x 10^{-6} W in the bandpass of 0.1 to 5 Hz. Signal common-mode rejection is 59 dB, and the effects of power supply variations are negligible. Power requirements are less than 1 W. Operating temperature is from -60 to +60°C. By using a special filter, the amplifier is capable of amplification in the 0.01 to 40-kHz bandpass. Using analog output, the amplifier has a voltage gain of 10K and a dynamic range of 57 dB; using broad-band FM carrier output, it has a modulation sensitivity of 464 Hz/mV and a dynamic range of 60 dB.

Development of the solid-state amplifier was completed during the last reporting period. Technical Report No. 64-73 was completed and 50 copies were sent to AFTAC for distribution during this reporting period.

6. DIGITIZER, TASK 1e

6.1 SHORT-PERIOD DIGITIZER

The short-period digitizer development and technical report were completed during the last reporting period. Fifty copies of TR 64-65 were sent to AFTAC for distribution.

This instrument (figure 8) is an analog-to-digital converter designed for use with a phototube amplifier (PTA). The digitizer samples the PTA output 50 times per second and converts each sample into a 12-bit natural binary number and presents this information in parallel form. The digitizer operates on batteries with a power consumption of 1.1 W. The frequency response is from dc to 10 Hz over a temperature range of -50 to +50°C. The digitizer, comprised of seven plug-in cards, may be incorporated in a galvanometer phototube amplifier or packaged as a self-contained unit for use with a separate amplifier.

6.2 LOW-POWER DIGITAL RECORDER

Development of the low-power digital recorder continued during the reporting period. Test results with various films have shown that 124 tracks of digital information can be recorded across the film perpendicular to the time axis.

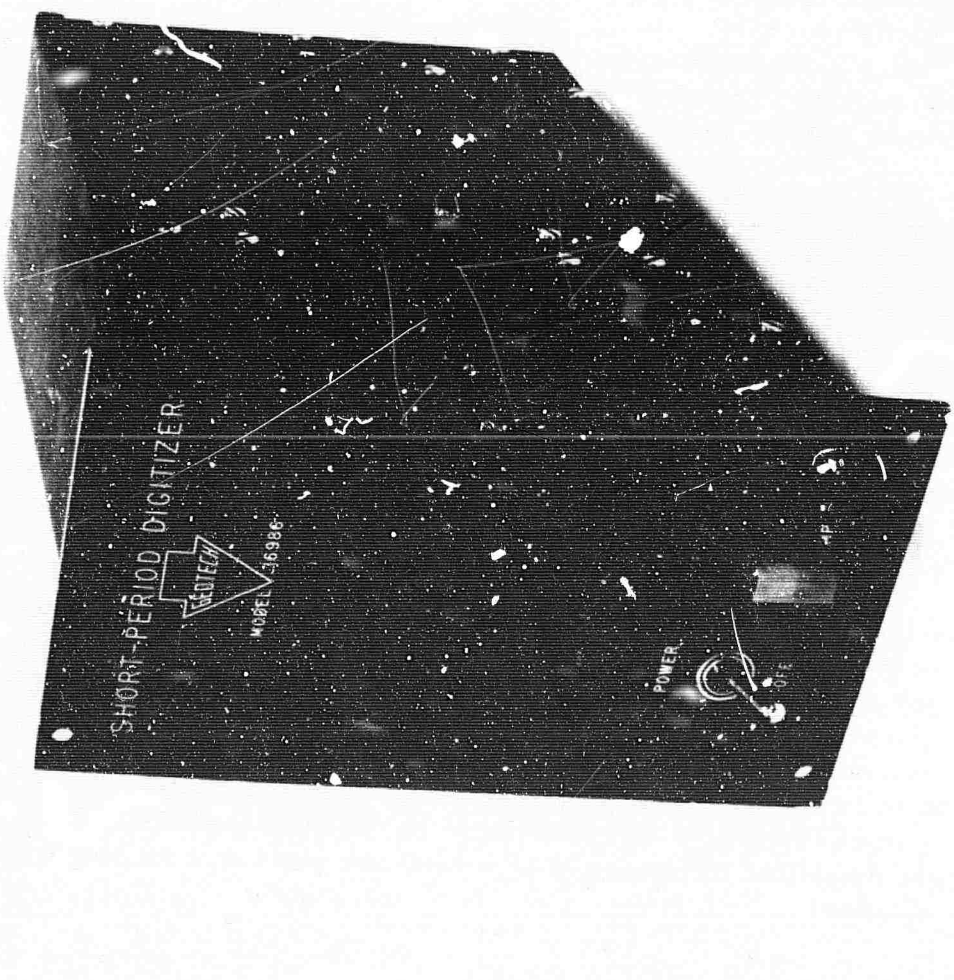

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Figure 8. Rack mounting case for digitizer

The outputs of 10 separate short-period digitizers may be recorded simultaneously in parallel form. The instrument (figure 9) uses 16-mm film as the recording medium and will operate unattended for 24 h. The film is stored in light-tight magazines containing both the "feed" and "take-up" spools. Under operating conditions, the magazines will be preloaded to facilitate field handling. Processing will be performed at a central location under controlled conditions to obtain uniform characteristics.

The recording head (figure 10) is composed of 124 individual fiber optic "light-pipes" imbedded in plastic. Each fiber is 0.1 mm in diameter, spaced at 0.127-mm intervals across the film. Excitation of each fiber is accomplished by individual neon lamps mounted on a printed circuit card.

The film transport and electronics drawer is rack mounted in a console for laboratory testing and evaluation. The prototype instrument will be repackaged for portability. The development of this device is approximately 75% complete and additional funds are required to continue the investigation of digital storage techniques.

6.3 READER AND CONVERTER

The design of the reader-converter was completed and some of the mechanical parts were fabricated. Most of the film transport parts in the digital recorder are interchangeable with this instrument. The development of the reader-converter is approximately 25% complete. Additional funds are required to continue the investigation of digital storage techniques.

7. NEW METHODS OF SIGNAL PRESENTATION, TASK 1f

Development of the array processor and Lissajous display device was completed during the last reporting period and TR 64-69, describing the instrument, was distributed in July.

The instrument (figure 11) is a seismic signal display device which may be used to introduce time delays in the signal channels. Time delay or advance is performed by physically displacing recording dots on the front of a cathode ray tube (CRT) parallel to the time axis. The face of this CRT is continuously

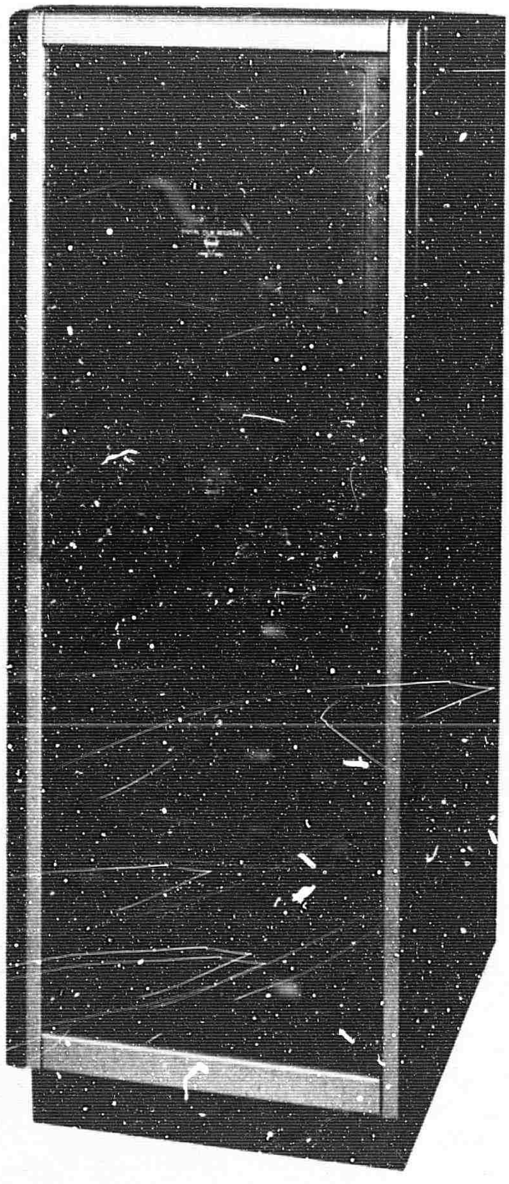

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Figure 9. Digital film recorder

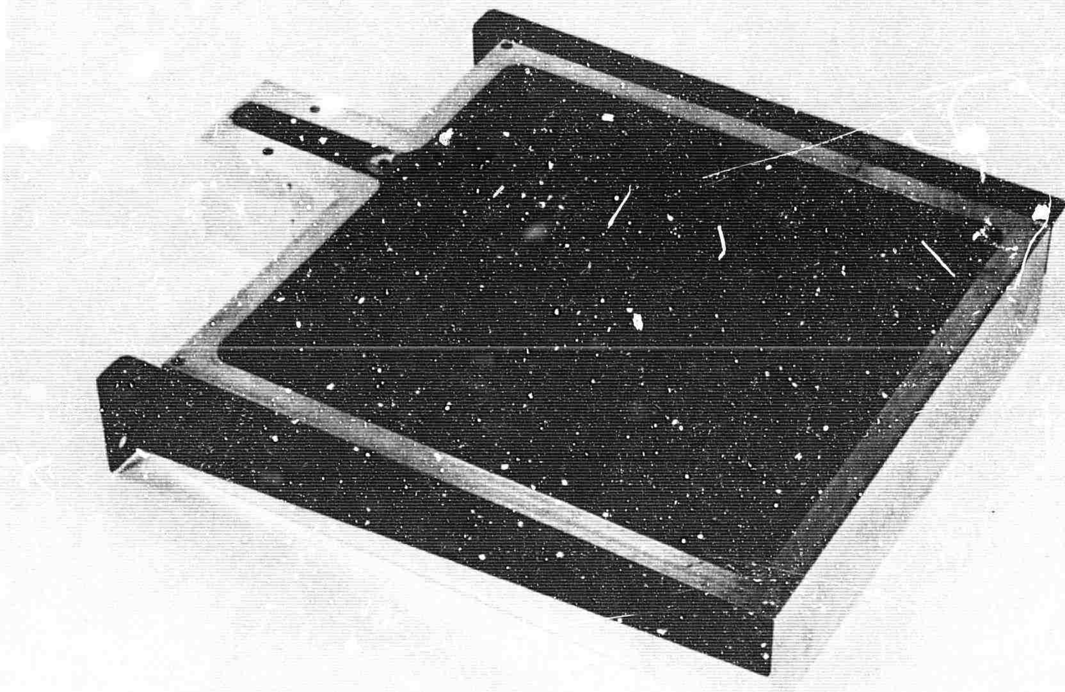

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Figure 10. Digital film recording head

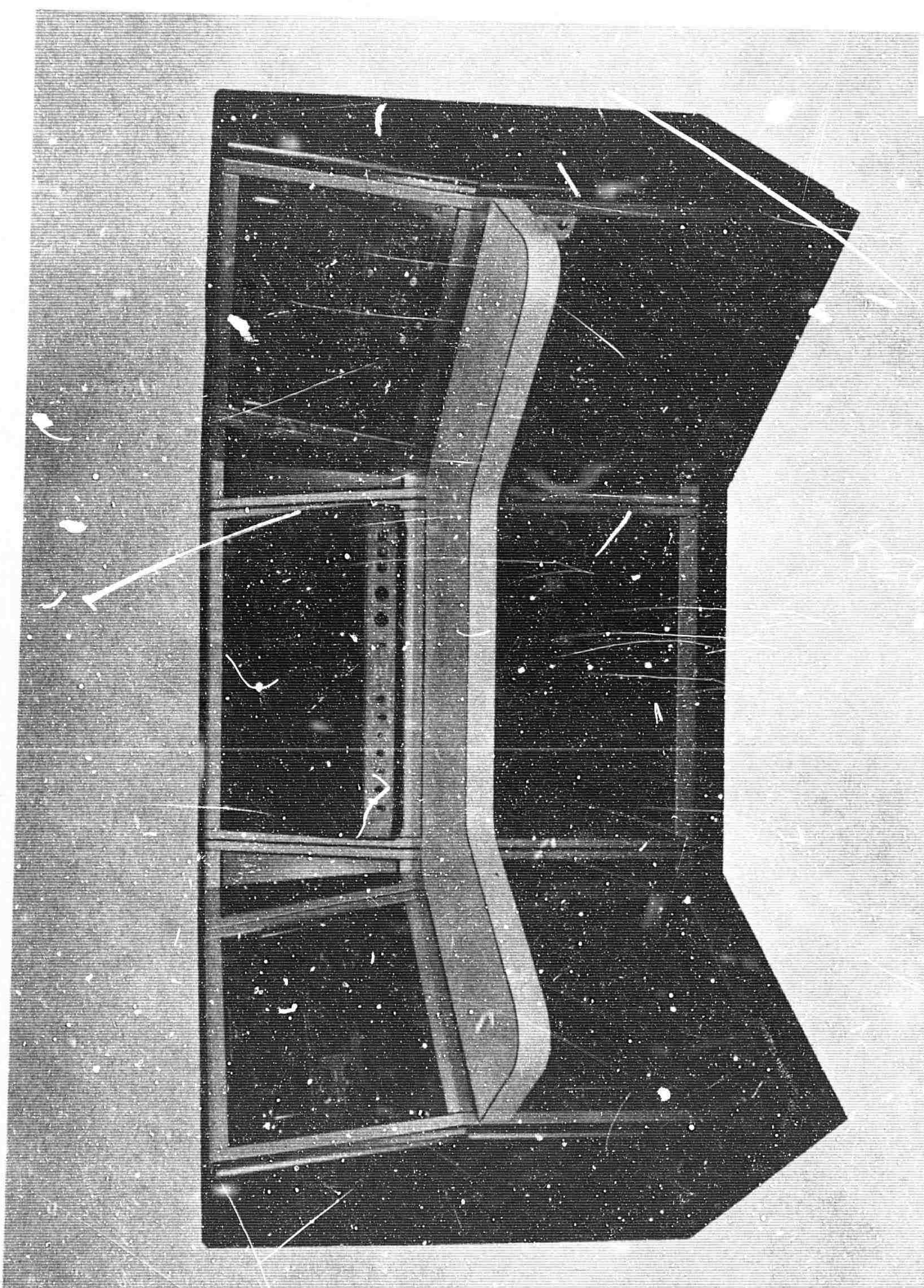

Figure 11. Array processor and Lissajous display

photographed and recorded on 16-mm film. After processing, the image is projected on a viewscreen at X20 magnification. The instrument has the capability of recording up to 60 channels of analog information simultaneously.

The system may be operated in one of five modes which are analog, X-axis deflection, Z-axis deflection, optical summation, and Lissajous display.

8. IMPROVED SEISMOMETER TEST FACILITIES, TASK 1g

An improved shake-table system (figure 12), which includes vertical and horizontal tables, was developed, tested, and calibrated. The system has an electrohydraulic drive that can be controlled by magnetic-tape playback. Large steel diaphragms in the suspension systems provide high spring rates and restraint against nonaxial motions. Motion monitors permit accurate determination of wave type, phase, and table amplitude. Displacement of the vertical and horizontal tables are calibrated by use of an optical flats calibrator and a capacitance micrometer, respectively.

Development of this system was completed during the last reporting period. Technical Report No. 64-78 was completed and 50 copies were sent to AFTAC for distribution early in this reporting period.

9. STABLE TABLE, TASK 1h

Laboratory testing of the components and closed-loop system tests of the single-degree-of-freedom stable table were completed during the last reporting period. Technical Report No. 64-20, describing the development and testing of this instrument, was written and distribution was made ea[illegible] in this reporting period.

The single-degree-of-freedom stable table (figure 13) is a test platform designed to support seismometers and similar motion-sensitive equipment weighing up to 225 kg. The platform is stabilized against vertical earth and live-load disturbances by an electromechanical servo-feedback loop. Stability is achieved over the 0.01 to 50 Hz bandpass with a maximum of 42 dB isolation at 0.5 Hz.

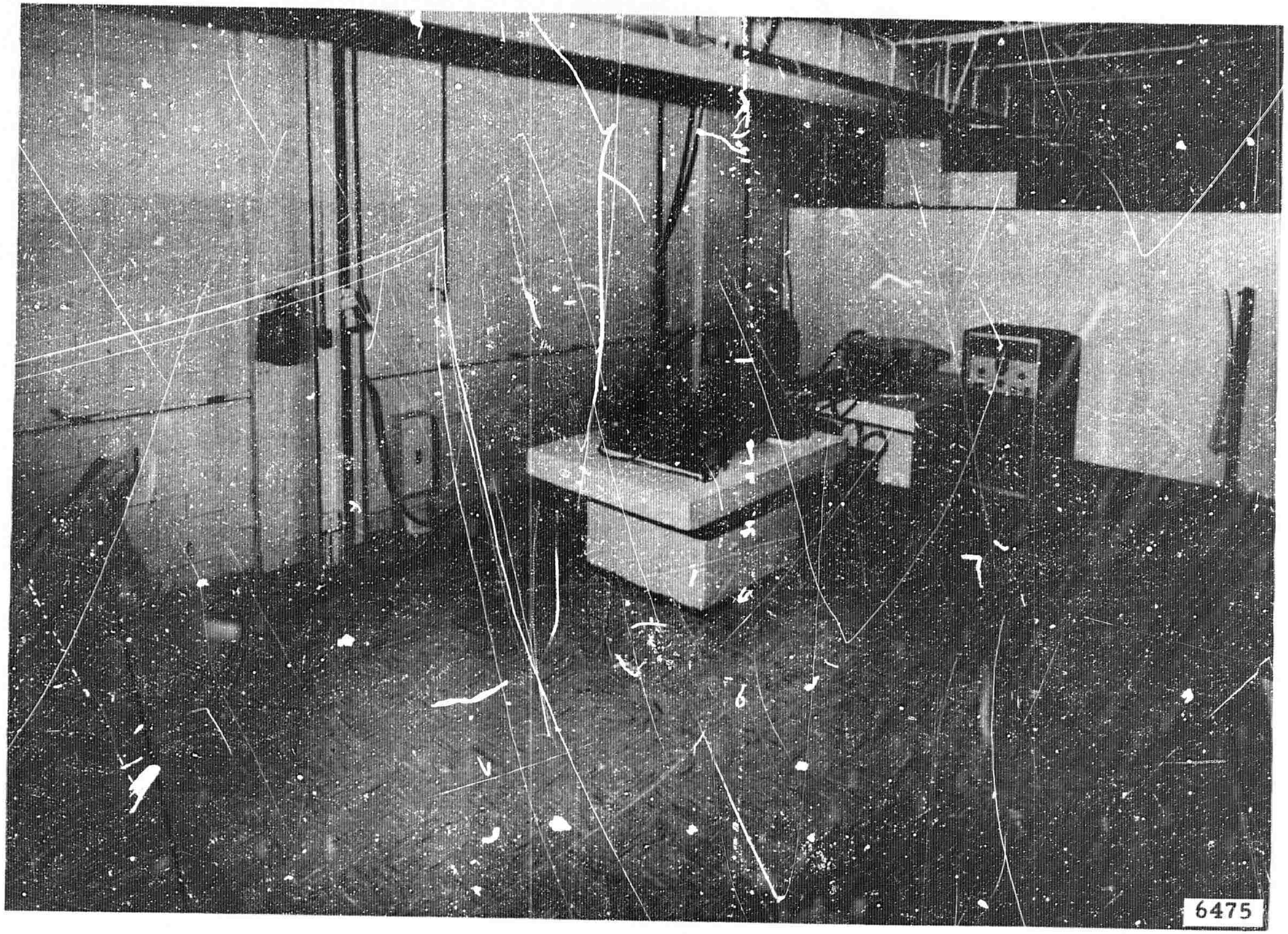

Figure 12. Seismometer shake-table laboratory

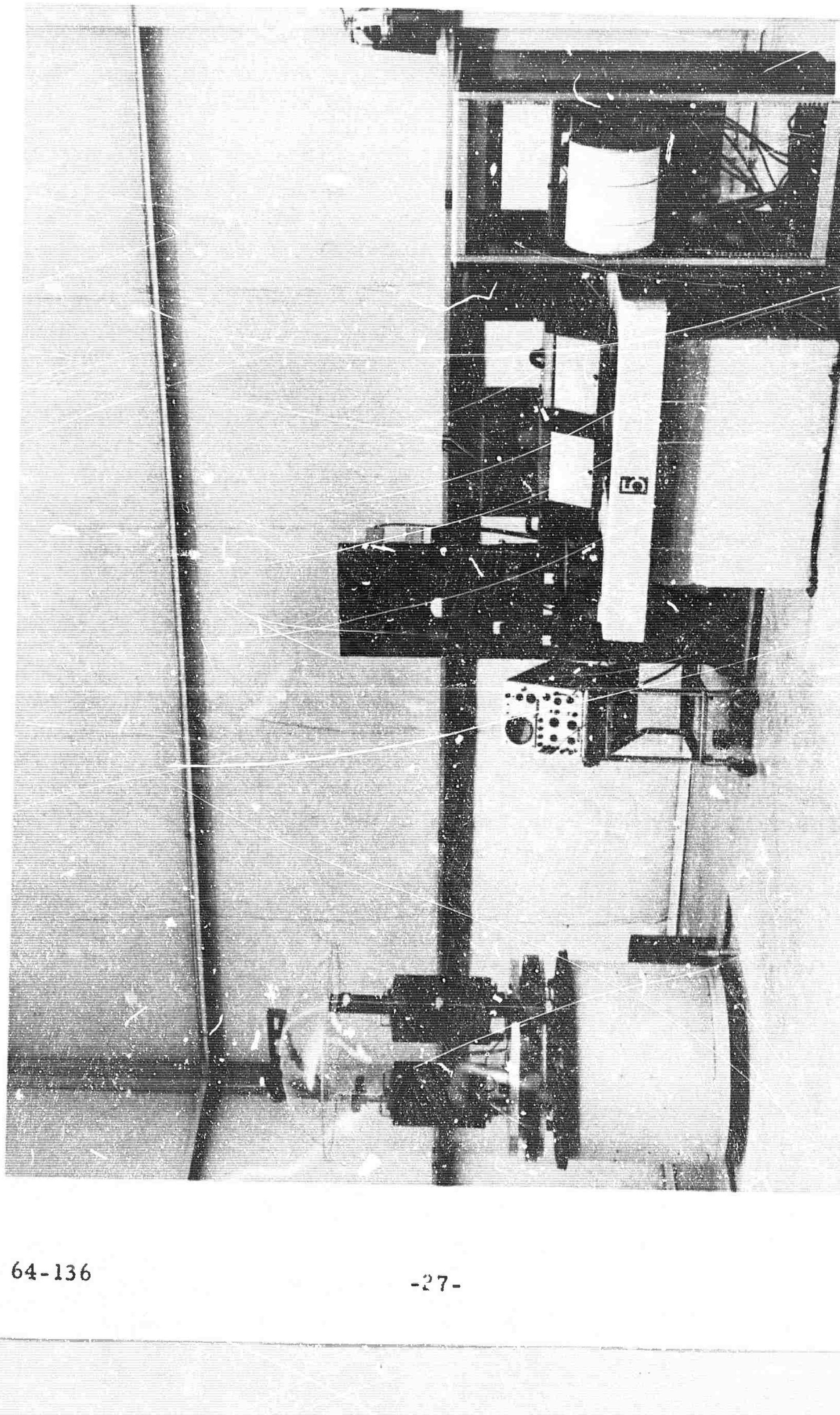

Figure 13. Single-degree-of-freedom vertical stable table

10. STRAIN SEISMOGRAPH, TASK 1i

Technical Report No. 64-54, describing the strain seismograph, was completed during the last reporting period, and 50 copies were sent to AFTAC for distribution.

In this report, the installation, instrumentation, and test results of preliminary tests of horizontal strain seismometers at WMSO are discussed. The major problems encountered during installation are reported.

The results obtained from seismograms of various combinations of inertial seismometers and horizontal strain seismometers are presented. Seismograms show that the summed crossed-horizontal strain seismograph is omnidirectional in response to Rayleigh waves and cancels Love waves in accordance with theory. The results of the summation of vertical pendulum and crossed strain signals show good cancellations of microseisms for some periods of time; at other times there appear to be no cancellations.

11. EXPERIMENTAL INVESTIGATION OF THERMAL NOISE, TASK 1j

An interim technical report (TR 64-127) was completed, and 50 copies were shipped to AFTAC in December 1964. The report describes the work accomplished on the experimental investigation of thermal noise of seismographs. Work on this project is incomplete. The technical report presents the proposed investigation, the present status of the project, and recommendations for the completion of the project.

The torsional pendulums that will be used to simulate the seismometer and/or galvanometer of a seismograph have been partially completed (figure 14). The fused silica spheres to be used for the inertial mass of the pendulums have been received. Tools for lapping the mirror facets on the spheres have been made, and lapping the facets is the next step in their preparation. The surface of the spheres will then be metallized with silver.

The coils for providing the magnetic field for the pendulums have been designed, but have not been wound.

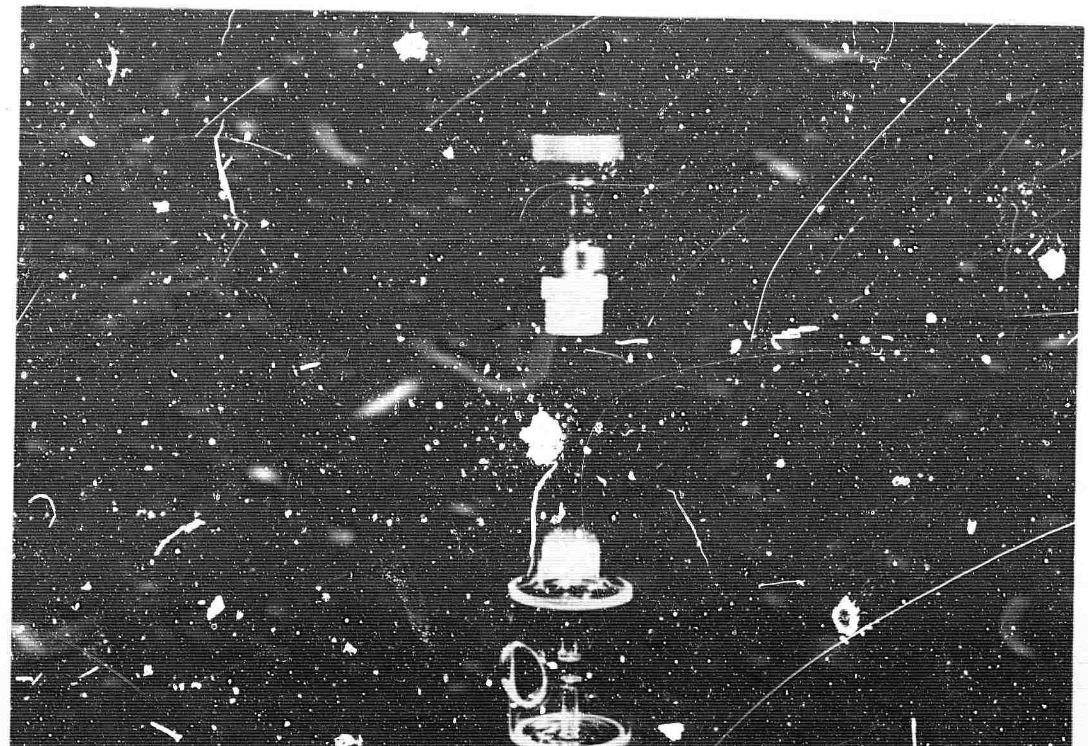

Figure 14. Partially assembled pendulum

The modifications of the photocell amplifier are essentially complete (figure 15). Minor changes in the electrical wiring and addition of a gain control must be made. The light source and all optics are complete and ready for the experiment (figures 16 and 17). Recording equipment is available.

Upon completion of the pendulums and the amplifier, experimental work can begin. Additional funds are required to continue the investigation of thermal noise in seismometers and galvanometers.

12. ADMINISTRATION

The work described in this report was accomplished under the direction of James R. Womack. The following personnel made major contributions: F. P. Kissinger, R. E. McMillan, B. M. Kirkpatrick, J. C. Massé, R. R. Staton, J. E. Keele, C. S. Montgomery, T. R. Thomas, J. C. Moore, S. N. Heaps, S. F. Griffin, C. L. Garrett, J. D. Kerr, and R. C. Shopland.

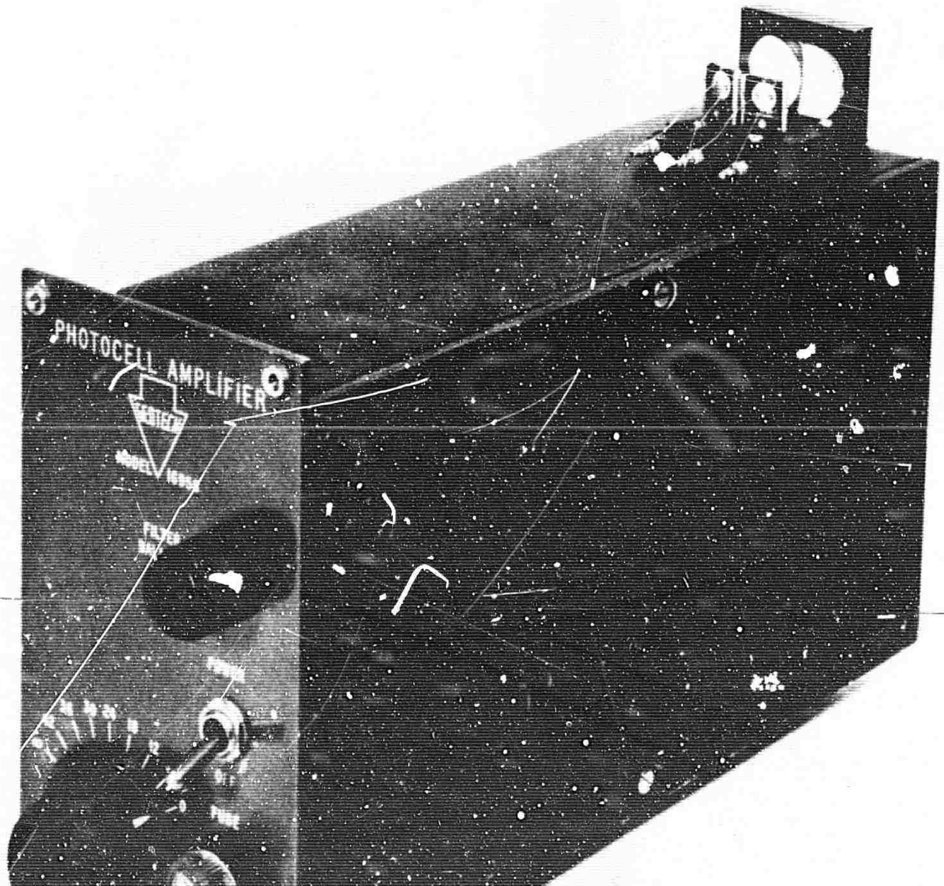

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Figure 15. Modified photocell amplifiei

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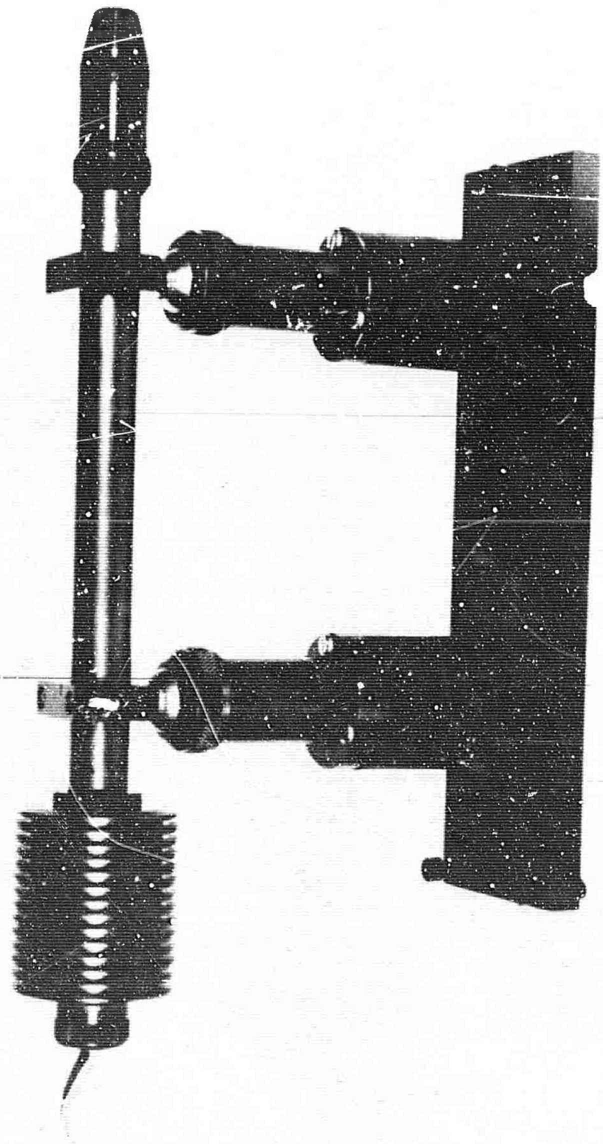

Figure 16. Light source

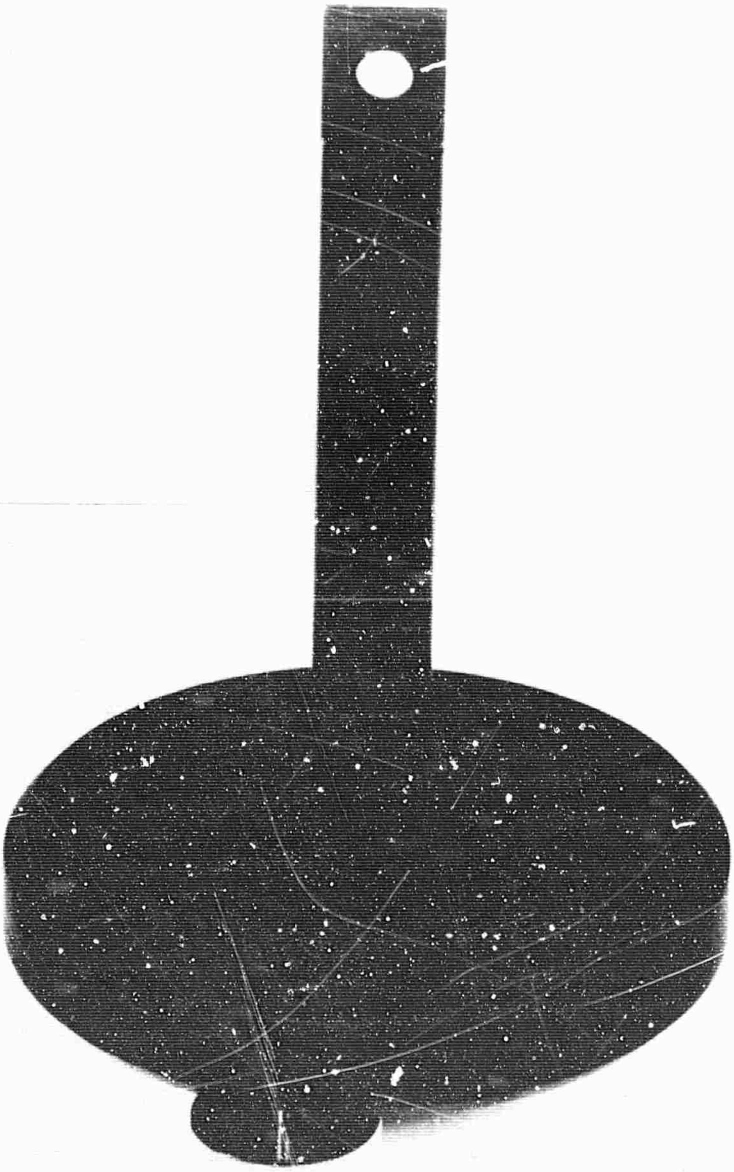

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Figure 17. Transfer lens and stand

APPENDIX to TECHNICAL REPORT NO. 64-136

WORK STATEMENT - PROJECT VT/072
CONTRACT AF 33(657)-9967

WORK STATEMENT - PROJECT VT/072
CONTRACT AF 33(657)-9967

1. TASKS

a. Inclined Seismometers

Continue the development of inclined and triaxial seismometers both short and long period, to obtain the following characteristics:

(1) Short-period triaxial: Devise a short-period triaxial seismometer in a cylindrical case having an outside diameter not greater than 5 inches. It is contemplated that this device will consist of three modules, stacked vertically one above the other, and oriented so that the direction of motion permitted each active mass, with respect to the frame, is orthogonal to the other two directions. These directions should be approximately 55 degrees from the vertical. The free period of each seismometer element should be approximately 1.25 seconds. Each suspended mass should be not less than 5 kilograms. Each module should carry its own calibration device, preferably of the electro-dynamometer type. It is desirable, but not mandatory, that the external resistance required for 0.7 critical damping be 300 ohms or more for each electrical output.

(2) Long-period triaxial: Carry forward the design and testing of the long-period triaxial seismometer. It is expected that this instrument will require a case of larger diameter than the short-period triaxial, and that the three mass-spring combinations will be arranged at the same level in the case, rather than being stacked vertically. It is desirable that natural periods within the range from 10 to 20 seconds be attained. Calibrator coils should be provided on each of the elements sensing in the three orthogonal directions. It is suggested that a small electrical heating element, drawing perhaps less than 1 watt, be incorporated in the inside of the case at the highest point, to induce thermal stratification of the air inside the case, should this become necessary.

(3) Electrical networks for directional reorientation: Devise electrical networks which, when connected to the triaxial seismometers, or to the amplifiers used for these devices, will permit alteration of the directions sensed by the triaxial seismometer to other directions desired for recording.

b. Galvanometers

(1) Study the design of galvanometers as applied to seismograph systems, with the objective of learning the limitations imposed on system design by ~~galvanometer air damping and determining the~~ changes in galvanometer design will lead to a reduction in this effect.

(2) Continue the investigation of power level recording through the application of wattmeter-type of galvanometers.

(3) Investigate the problem of improving galvanometer resolution by optical and other methods. This investigation should include a practical means of effecting an extension of the optical-lever arm of a galvanometer so that a smaller rotation of its coil may be resolved with a given photographic or photo-electric sensing system. This is an important step in achieving effective sensitivity with the digitizing system already under investigation.

(4) Determine the feasibility of using fluid damped galvanometers, wherein the density of the coil is approximately equal to the density of the damping fluid, for reducing the response of galvanometer-phototube amplifiers to external vibrations.

c. Filtering

(1) Investigate the alteration of galvanometer parameters for shaping seismograph response characteristics. This investigation should also include the study of a rejection filter whose frequency is servo-controlled by microseisms.

(2) Conduct appropriate laboratory and field tests to determine the feasibility of using a combination of low-frequency and high-frequency galvanometers driven by a single seismometer to form a broad-band seismograph in which the response can be easily shaped to reduce unwanted microseismic noise.

(3) Complete the development of a system suitable for filtering of seismic data either in real time or when played back from magnetic tape at X10 or X100 speed-up. The filter shall cover a frequency range of 5 decades at each multiplier setting and provide adjustable high-frequency and low-frequency cut-off points and cut-off rates.

d. Amplifiers

Continue the investigation of amplification methods and available commercial amplifiers which might be made suitable for routine use in seismograph systems operating in the frequency band of 0.01 to 100 cps. Noise level, gain, stability, reliability, power requirement, bandpass and dynamic range are among the factors to be considered. Strive particularly to obtain a practical amplifier consuming less than 1 watt of power, whose output is a frequency-modulated signal in the audio range. This investigation may include some measurements of the low-frequency components of transistor noise.

e. Digitizer

(1) Continue development and construct practical instrumentation for the conversion of seismic signals in the passband from 0.01 to 10 cps into digital form. Power requirements, dynamic range, resolution, recording methods, cost, reliability and operation by untrained personnel are among the factors that must be considered. It seems possible that the improvement of galvanometer resolution by optical means, as suggested under 1b above, will be important in this connection.

(2) Adapt an Automatic Processing Recording Camera (Develocorder) or slow-speed magnetic-tape recorder for recording several channels of digital data along with analog data. Low-power consumption, reliability, and economy of operation are important considerations.

(3) Design an appropriate reader and converter component of this digital system to provide a punched paper-tape output.

f. New Methods of Signal Presentation

(1) Devise a time compensated signal display method suited for use with a considerable number of detectors deployed over an area of sufficient size to cause the transit time of a signal across the array to be several seconds.

The display contemplated will make use of a cathode-ray oscillographic tube whose screen is continuously photographed by a Develocorder. The method involves the introduction of pseudo-time delays into detector signal channels by electrical displacement of recording spots in the direction of the time-axis of the recording film. A sampling method is contemplated, whereby rapid switching from one detector signal to another is performed either mechanically or electrically, a hundred output samples or more being provided at a rate of 30 times a second or faster.

In one of the possible displays, a dot pattern shall be created, whereby exact coincidence of several signal waveforms will produce a nearly solid line of dots representing a single combined waveform, whereas lack of signal coincidence (as displaced along the time axis) resulting from nonmatching waveforms, will produce a scattered pattern of dots.

(2) Devise, if possible, an arrangement whereby electronic oscilloscope tubes may be incorporated into the Develocorder so that their spots may record as Lissajous figures on the 16-mm film. It is intended that the arrangement be such that at least a few of the standard galvanometer-produced traces shall be recordable at the same time. The intent is to provide a means for continuous presentation of earth-particle motion by suitable combinations of seismometers, amplifiers, and electrical resolving circuits.

(3) Investigate methods of visually monitoring and selectively recording seismic data being played back from magnetic tape. The recording shall be approximately 11 inches wide and the time scale shall be such that a 10-cps signal can be resolved. The "hard copy" shall be processed automatically (such as the Xerox process) and be available for immediate use.

g. <u>Improve Seismograph Testing Facilities</u>

Continue the improvement of existing Government-owned seismograph testing facilities to include:

(1) Redesigned vertical and horizontal shake tables, with table motions which can be controlled by playback of magnetic tapes;

(2) Improved monitors and calibration devices to show and record the motion of the shake tables when desired;

(3) Other such improvements as may be accomplished without extensive engineering effort, and as the Project Officer may direct.

h. Stable Table Design

Following the design concepts of the National Bureau of Standards, build an experimental stable-platform installation of sufficient size to accommodate a load of 500 pounds.

i. Strain Seismograph

(1) Expand the cross-horizontal strain seismograph currently being installed at WMSO to include an additional crossed horizontal strain seismometer located at 45 degrees with respect to the first. Combine the output of each horizontal strain member with the output of a horizontal inertial seismometer as suggested by Dr. Benioff to form a total of eight combinations each of which has a directional response along a specified azimuth.

(2) Combine the output of a vertical inertial seismometer with the output of a pair of horizontal strain seismometers as suggested by Dr. Romney to determine the feasibility of improving the signal-to-noise ratio for P waves.

(3) Conduct further investigations of the capability of the array of strain seismographs for improving signal-to-noise ratio and for discriminating between waves of different vibrational modes. Determine design improvements of the strain seismograph and perform operational evaluation at permanent seismic stations.

j. Experimental Investigation of Thermal Noise

Following work by NBS and the pertinent literature, devise and carry through experiments with the object of measuring noise components in seismograph systems due to Brownian motion, Johnson noise, and other evidences of thermal agitation.

2. TECHNICAL DOCUMENTS

a. Upon request of the AFTAC Project Officer, furnish two sets of reproducible engineering drawings and specifications for any new equipment designed. These drawings and specifications shall be suitable for use by a manufacturer of like items.

b. Original seismograms obtained in the performance of work under subparagraph 1i, above, will be forwarded to AFTAC upon completion of this specific task.

3. REPORTS

a. Monthly letter-type progress reports in 12 copies, summarizing work through the 25th of the month will be dispatched to AFTAC by the end of each month. Specific topics will include technical status, major accomplishments, problems encountered, future plans, and any action required by AFTAC. Illustrations and photographs should be included as applicable. The heading of each report should contain the following information:

AFTAC Project Number
Project Title
ARPA Order No. 104-60
ARPA Project Code No. 8100
Name of Contractor
Date of Contract
Amount of Contract
Contract Number
Contract Expiration Date
Project Scientist or Engineer's name and phone number

b. A list of suggested milestones will be dispatched to AFTAC in 12 copies within 20 days following award of a definitive contract. (Milestones are defined as points of accomplishments which present significant progress when completed). For a given milestone, the list should include the completion date and a brief description, when necessary, to define specifically the accomplishment to be attained thereunder. Upon approval of milestone information, copies of SD Form 350 will be made available for use in reporting progress against the milestone schedule. The SD Form 350 will be attached to the monthly report.

c. Special reports of major events will be forwarded by telephone, telegraph, or separate letter as they occur and should be included in the following monthly reports. Specific items are to include (but are not restricted to) program delays, program break-throughs, and changes in funding requirements.

d. A semiannual technical summary report in 20 copies, covering work performed through 31 December and 30 June will be submitted to AFTAC within 35 days following the close of the reporting period. These reports will present a concise and factual discussion of the technical findings and accomplishments of the reporting period. The heading of the report will contain the heading information indicated in paragraph 3a, above.

e. A final technical report in 50 copies will be submitted within 60 days following completion of each task. The heading of the reports will contain the information indicated in paragraph 3a, above.

4. MISCELLANEOUS

All technical documents and reports called for under paragraph 2 and 3, above, are to be submitted to:

HQ USAF (AFTAC/TD-1)
Washington 25, D. C.